

## A SEMI AUTOMATED EMPIRICAL MODEL FOR ESTIMATION OF CH<sub>4</sub> EMISSION USING COARSE RESOLUTION THERMAL DATA

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**KEY WORDS:** Land Surface Temperature, NDVI, SWM, MODIS, wetlands, and methane.

### ABSTRACT:

Concentration of atmospheric methane is considered to have a significant effect on climate because of its GWP (Global Warming Potential), which is 21 times of CO<sub>2</sub>. Methane is generated by the process of methanogenesis under wet anaerobic conditions, oxidation by methanotrophic bacteria and transportation to the atmosphere. Wetlands are the major source of methane emission, because of the presence of anoxic conditions, organic material content and large area. They contribute approximately 22% to the global methane budget. In addition to wetlands, landfills, rice paddies and termites etc. are the other major sources of methane emission. However, there is a high degree of uncertainty about the actual contribution of all these methane-emitting sources to the total methane budget. In the present study a Semi-automated Empirical Methane Emission Model (SEMEM) has been developed and used for estimation of methane from wetlands using MODIS (Moderate Resolution Imaging Spectroradiometer) data. Model has two key factors, namely, temperature and productivity. Productivity and fluxes have been taken from literature and used as inputs for different methane emitting sources. Area extent of different wetlands has been estimated based on knowledge-based classifier using NDVI, optical bands (1,2, 3) with thermal channel (31 and 32) data. As methanogenesis is a temperature dependent process, the model makes use of LST (Land Surface Temperature) which has been generated using Split Window Method (SWM) of first order approximation. A Semi-automated Empirical Methane Emission Model (SEMEM) has been developed for estimation of methane emission from wetlands. Based on the analysis of MODIS data, methane emission from wetlands has been estimated for India pertaining to the months of May 2005 and October 2005. Results shows that emitted methane in the month of May 2005 was 10515 kg with 29419 sq.km total methane emitting area whereas in the month of Oct 2005 total emitted methane was 38069 kg with 93995 sq.km methane emitting area.

### 1. INTRODUCTION

Wetlands are the areas on the landscape where land and water meet and usually lie in depressions or along rivers, lakes and coastal waters. Wetlands are broadly defined as "a variety of shallow water bodies and high ground water environments that are characterized by permanent or temporary inundation, soils with hydric properties, and plants and animals that have adapted to life in saturated conditions". They generally include lakes, ponds, floodplain wetlands, impoundments (tanks, reservoirs), mud/tidal flats, and mangroves, besides lowland paddies. Wetland ecosystems in recent years have acquired added importance due to their role in biogeochemical cycling and as sources and sink of green house gases especially the methane.

Wetlands in India are distributed in all the ecological regions. Varying estimates of wetland area have been given by different agencies/authors. According to an estimate by Ministry of Environment and Forests (1992) wetlands occupy about 4.1 million ha area excluding mangroves in the country (Anon. 1992). A recent scientific estimate using satellite remote sensing data by Garg et al (1998) puts wetlands area in the country at 8.27 Mha. This excludes paddies and river/canals. Out of this inland wetlands account for 4.02 Mha.

Wetlands are one of the most important sources of atmospheric methane (CH<sub>4</sub>), the most significant GHGs after CO<sub>2</sub>, having 21

times global warming potential than that of CO<sub>2</sub>. Wetlands provide a habitat conducive to methane producing (methanogenic) bacteria that produce methane during decomposition of organic material. These bacteria require environments with anoxic and abundant organic matter, both of which are present in wetlands conditions.

Emission of methane from wetlands is dependent on climate/weather conditions such as temperature and humidity besides water spread. Objective global estimates of methane from wetlands are still not available due to non-availability of temporal data on "extent and types of wetlands". Not only methane but also some other GHGs like N<sub>2</sub>O, CO<sub>2</sub>, H<sub>2</sub>S etc are released from the wetlands in small but varying amounts. There have been several attempts to use measured rates of emission from wetlands for global CH<sub>4</sub> emission (Matthews et al, 1987 and Sheppard et al, 1982). Quite a few studies have also used process-based models (Cao et al., 1996, Walter et al., 2000 and Walter et al., 2001) for methane emission. Matthews and Fung (1987) estimate 110 Tg/yr from wetlands, whereas according to IPCC (1998) since 1750 atmospheric concentrations of methane have increased by 150 percent in 1998 from approximately 700 to 1,745 parts per billion by volume (ppbv). Among the wetlands, tropical wetlands contribute 60% of methane emissions whereas wetlands in the northern latitudes emit about 35%. High emission from tropical wetlands is primarily due to the higher temperatures in the tropics in comparison to other regions. Tropical wetlands actively

produce and emit methane continuously due to flooded conditions.

MODIS (Moderate Resolution Imaging Spectroradiometer) is an EOS instrument, which scans earth  $\pm 55^\circ$  from nadir in 36 spectral bands with 250m (1 and 2 bands), 500m (3-7 bands) and 1km (remaining bands) resolution ranging from the visible wavelength to the thermal infrared (TIR) with 2330 km swath. MODIS provides images of daylight reflection and day/night emission of the earth surface, repeating global coverage every one or two days. MODIS has utility to monitor the changes in land surface on global/ regional scale because of high temporal resolution and wide swath.

In the present study, a Semi-automated Empirical Methane Emission Model (SEMEM) has been developed to estimate the methane emission from wetlands and waterlogged areas. This model requires classified wetland areas from satellite data, LST from MODIS (or other satellite), flux (measured or from literature and productivity). This model has been used for estimating the emitted methane from entire country in two different months May 2005 and Oct 2005.

## 2. STUDY AREA

For this present study methane emission for whole India including island territories has been estimated. India has a wide physiographical extent and lies in between  $8^\circ$  Lat to  $36^\circ$  lat and  $66^\circ$  long to  $100^\circ$  long having different physical features like Great Himalayas, Plains, Plateaus, Alluvial plains like Gangetic, Brahmaputra etc.

## 3. DATA USED

MODIS data of May2005, and Oct2005 have been processed for whole country in the present study. Bands 31( $10.28\mu\text{m}$ - $11.72\mu\text{m}$ ) and 32( $11.78\mu\text{m}$ - $12.28\mu\text{m}$ ) are used for land surface temperature (LST) estimation whereas bands 1( $0.62\mu\text{m}$  –  $0.67\mu\text{m}$ ) and 2( $0.841\mu\text{m}$  –  $0.876\mu\text{m}$ ) are used for NDVI. LST, NDVI and MODIS 1,2 and 3 bands have been used for classification.

## 4. METHODOLOGY

The schematic of the adopted methodology is given in Fig.1

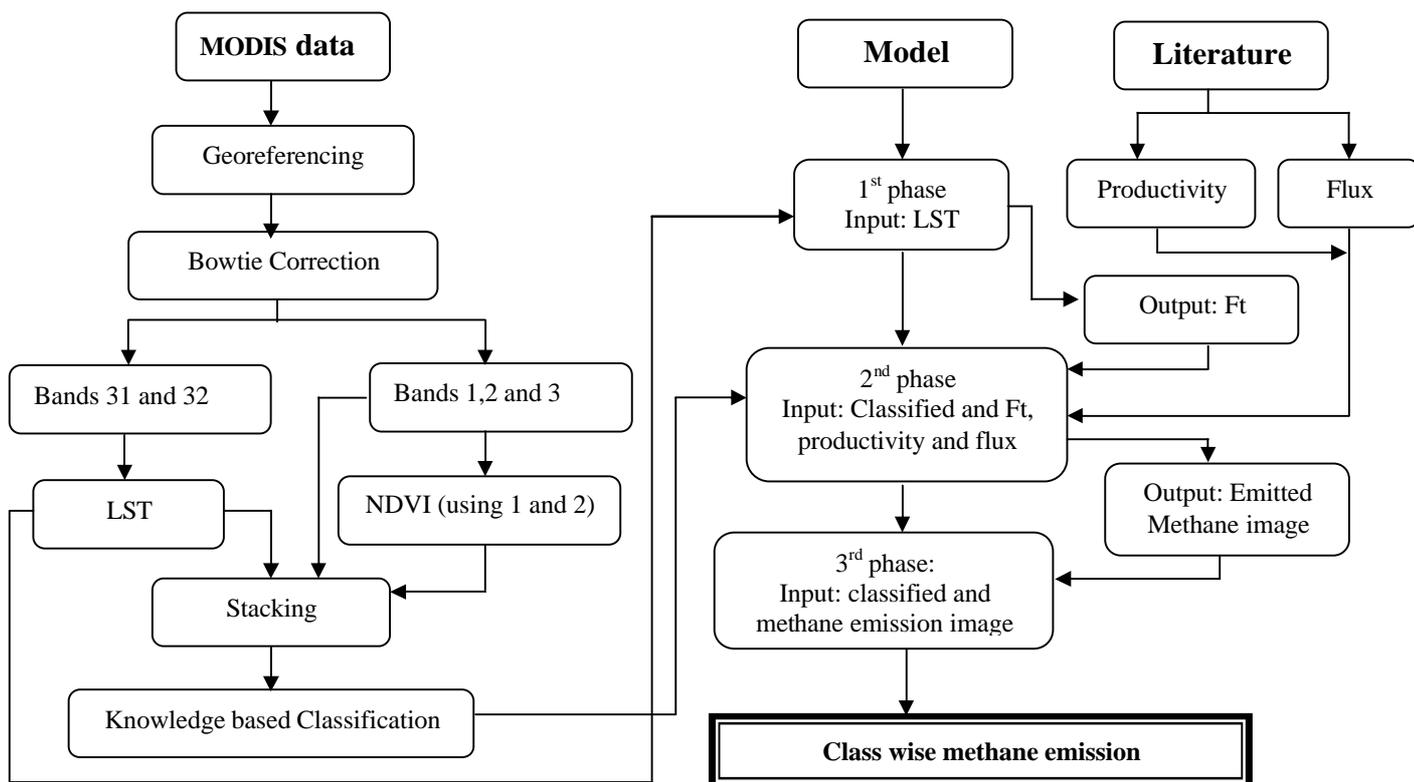


Fig 1: Schematic of Methodology

#### 4.1 Preprocessing

MODIS data has been georeferenced using geographic Lat/ Long projection with WGS 84 Spheroid. After that bowtie correction has been applied to rectify overlapping of adjacent scan lines. Subsequently, LST has been estimated using thermal bands 31, 32 and NDVI has been calculated using optical bands 1, 2. LST, NDVI and optical bands 1,2 and 3 were then stacked together for knowledge-based classification.

#### 4.2 Estimation of Land Surface Temperature

Land surface temperature (LST) is one of the important parameters for studying land surface. In the present study LST has been used as one of the major parameters for estimation of methane emission from wetlands. Various methods of LST determination such as Spectral ratio method (Watson, 1982), reference channel method, emissivity normalization method, alpha residue method (Li, 1999) and Split window method (Wan and Dozier, 1996; Wan, 1997) and Constant emissivity method (CEM) (Kahle, 1987) have been evaluated. However, one of the major problems encountered in estimating kinetic temperature of various land cover types is the emissivity. Split window method (SWM) corrects for atmosphere's effects based on the differential absorption in adjacent infrared bands. In the present study Split window method of first order using bands (31 and 32) MODIS data has been used for LST estimation.

This method uses thermal bands 31(10.78 $\mu$ m – 11.28 $\mu$ m) and 32 (11.77 $\mu$ m – 12.27 $\mu$ m) of MODIS data. First temperature is estimated using band 31 by making use of Planck's law and in 32 by the same law as mentioned below:

$$T = \frac{C_2}{I \left( \log \left\{ \frac{e \cdot C_1}{R \cdot I^5} + 1 \right\} \right)} \quad (1)$$

where,

$$C_1 = 2phc^2 = 3.74183 \times 10^{-16} \text{ wm}^2$$

$$C_2 = 1.4388 \times 10^{-2} \text{ mK}$$

$e$  = Emissivity

$I$  = Wavelength

$R$  = Radiance

Using first order approximation a linear equation (2) has been solved for estimating the coefficients a and b. Again using equation (3) Land surface temperature has been estimated.

$$(T_s - T_{32}) = a * (T_s - T_{31}) + b \quad (2)$$

$$T_s = (1/1-a) * (? T) + T_{31} + b \quad (3)$$

Where,

T<sub>31</sub> = temperature in band 31

T<sub>32</sub> = temperature in band 32

T<sub>s</sub> = surface temperature

? T = temperature difference between band 31 and 32

#### 4.3 Classification

Knowledge based classification has been used for classify wetland classes and waterlogged areas using LST, NDVI and optical bands 1, 2 and 3. Supervised classification was not found suitable for classify the various methane emitting classes due at national/regional level. Knowledge based classification is like decision tree classification, where decisions have to be made by researcher on the basis of different constraints. In the present study ranges of values are decided for various classes for each layer like LST, NDVI, and optical bands 1,2 and 3. Then, a multiple decision tree has been developed for satisfying all the ranges and constraints for each layer and for each class.

#### 4.4 Estimation of Methane Emission

Methane emission has been estimated using an empirical model (SEMEM). T factor (temperature related factor) is used to model the change in methanogenic activity as a function of temperature. Experiments have shown that the optimal temperature for the majority of methanogens ranges from 30<sup>o</sup>C to 40<sup>o</sup>C (Liu, 1996). Inclusion of productivity factor is based on the fact that methane emission is mainly driven by photosynthetic activity. Methane emission from wetlands is described by the following equation (modified from Liu, 1996):

$$E_{CH_4} = E_{obs} \cdot Ft \cdot A \cdot P \quad (4)$$

Where  $E_{obs}$  is the observed methane flux from different classes, Ft is T factor, A is area and P is productivity factor. Productivity and observed methane fluxes (Table.1) for all different classes have been used from Sheppard et al (1982).

Table 1: Productivity and Methane emission fluxes for different classes

Sources	Productivity	Flux (g/m <sup>2</sup> /year)
Water	0.25	3.5
Mud flats	1.00	2.25
Swamp/marsh	0.25	25.1
Salt flats	1.00	1.4
Rice paddy	1.00	6.8
High moisture	1.00	31.5

T factor has been defined by Liu (1996) as follows:

$$F_t = \frac{F(T_s)}{F(T_s)} \quad (5)$$

Where,

$$F(T_s) = \frac{e^{0.334(T_s-23)}}{1 + e^{0.334(T_s-23)}} \quad (6)$$

In the above equation T<sub>s</sub> is the temperature in <sup>o</sup>C, which has been calculated for each pixel using Split window method.

$\overline{F(T_s)}$  is the mean of F(T<sub>s</sub>) over land. Coefficients of this exponential equation have been taken from Liu (1996).

Subsequently, classified image and  $F_i$  image have been used for getting the class statistics for all classes. A semi-automated procedure incorporating all steps required for data analysis and methane estimation has been developed and used for the processing of MODIS data for India.

### 5. RESULTS AND DISCUSSIONS

An attempt has been to model the emission of methane from different methane emitting classes for India. A semi-automated empirical methane emission model has been developed incorporating land surface temperature, productivity, methane emission flux and area of methane emitting classes. Productivity and methane emission flux have been taken from literature (Sheppard et al, 1982). Two months (May 2005 and Oct 2005) MODIS data has been processed using the developed model and estimates of emitted methane have been obtained for six methane-emitting classes viz. water, mud flats, aquatic vegetation/swamp/marshes, salt flats, rice paddy and high moisture.

Thermal bands band 31(10.78 $\mu$ m – 11.28 $\mu$ m) and 32(11.77 $\mu$ m – 12.27 $\mu$ m) of MODIS data have been analyzed for estimation of LST using Split window method of 1<sup>st</sup> order approximation, while optical bands 1(0.62 $\mu$ m – 0.67 $\mu$ m), 2(0.841 $\mu$ m – 0.876 $\mu$ m) and 3(0.459 $\mu$ m – 0.479 $\mu$ m) along with LST have been used for NDVI calculation and knowledge based classification. A comparative study has been done using MODIS data of May 2005 and Oct 2005 to study the variation in the amount of the emitted methane from wetlands and waterlogged areas. Results are summarized in Table 2.

Table 2: Methane emitting areas and methane estimates in India

	May 2005		October 2005	
	Area (Sq.Km)	Methane (Kg)	Area (Sq.Km)	Methane (Kg)
Water	10587	769	37772	2423
Mud flats	5952	1365	9096	1995
Aq.veg/ swamp/marshes	5071	2852	20081	12829
Salt flats	6058	921	4838	706
Rice paddy	115	74	17657	11808
High moisture	1636	4534	4551	8306
<b>Total</b>	<b>29419</b>	<b>10515</b>	<b>93995</b>	<b>38067</b>

Annual methane flux (Sheppard et al, 1982) has been used for methane estimation. These values assume that the current Indian environmental conditions will remain same round the year. However, whether condition do keep on changing in various part of the year. Keeping this point, segmentation of yearly-emitted methane has been done to have an idea about monthly emission. Results shows that emitted methane in the month of May 2005 was 10515 kg with 29419 sq.km total methane emitting area whereas in the month of Oct 2005 total emitted methane was 38069 kg with 93995 sq.km methane emitting area. Fig.2a and 2b shows the classified image of India in the month of May 2005 and Oct 2005 respectively. Whereas Fig.3a and 3b shows the processed images through the described model for the month of May 2005 and Oct 2005 respectively which indicate the emission of methane from various methane emitting sources. Comparisons of the methane emitting area and estimated total methane from wetlands in two months are shown in Fig.4a and 4b.

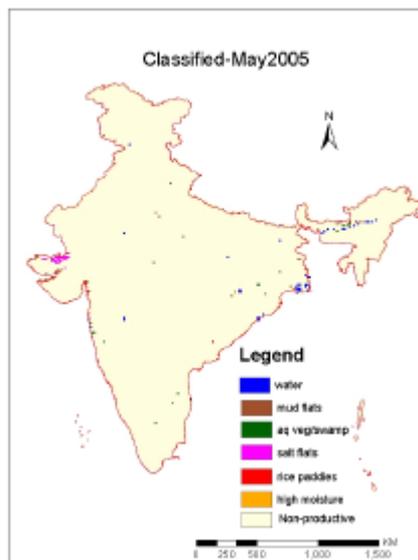
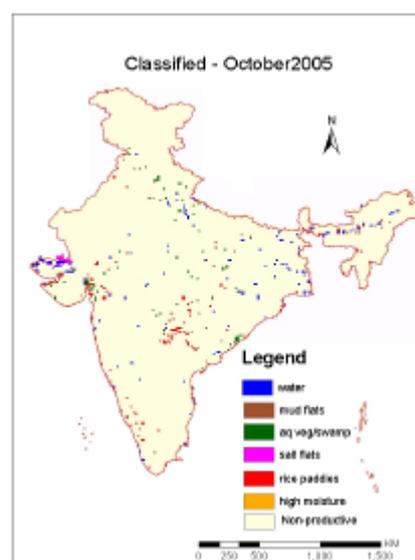


Fig 2a.



2b.

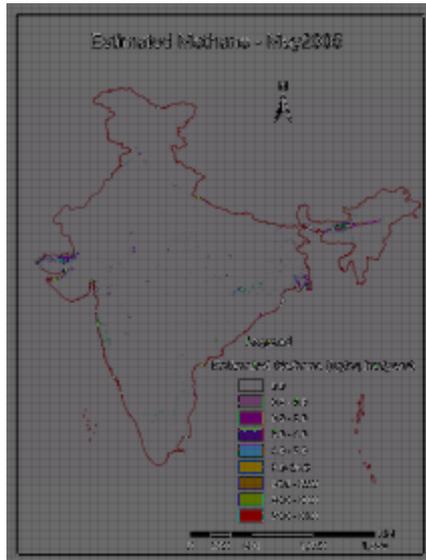
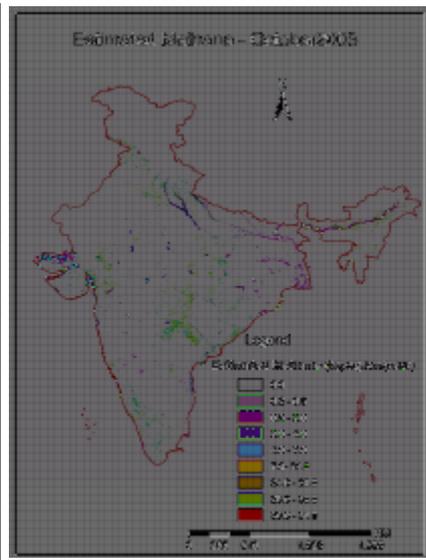


Fig 3a.



3b.

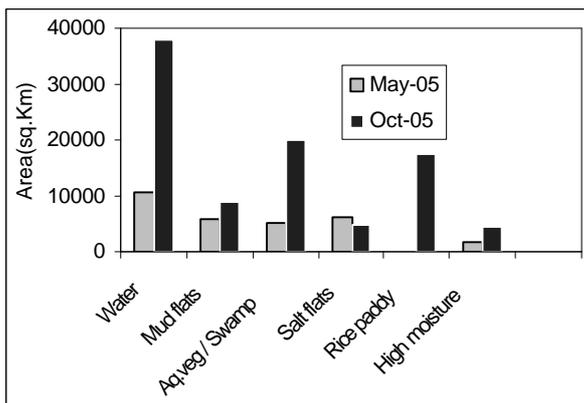
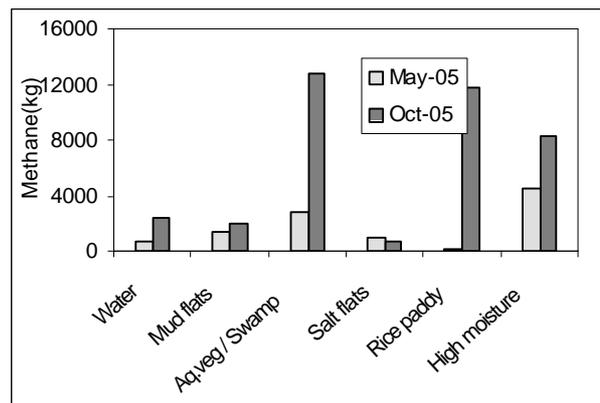


Fig 4a.



4b.

## 6. CONCLUSION

A Semi-automated Empirical Methane Emission Model (SEMEM) has been developed using temperature, productivity, area and observed methane fluxes for estimation of methane emissions. This model is sensitive to changing temperature, which is a most critical factor in methane emission. Based on this approach an assessment of methane emission from Indian wetlands and waterlogged area has been made.

Monthly emission is required for the assessment of annual global/regional methane emission budget from wetlands and other methane emitting sources. This work is a step towards attaining

an idea about monthly-emitted methane from wetlands of India for two months (May 2005 and Oct 2005). In this regard, MODIS data have been utilized to study land surface parameters like LST

and NDVI. This data has also been used for extraction of different methane emitting classes with LST and NDVI.

Results shows that emitted methane in the month of May2005 was 10515 kg with 29419 sq.km total methane emitting area whereas in the month of Oct 2005 total emitted methane was 38069 kg with 93995 sq.km methane emitting area.

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